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Keep an Eye on Information Processing: Eye Tracking Evidence for the Influence of Hypertext Structures on Navigational Behaviour and Textual Complexity

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1. Interpreting eye tracking data in the context of information processing

When interpreting eye tracking data, the metrics fixation duration, saccade lengths and the occurrence of regressions are used to infer moment-by moment processing of the text by the reader. Of course, these features of eye movements are also influenced by factors such as text difficulty caused by lexical or syntactic ambiguity. More difficult text leads to longer fixation durations, shorter saccades and more regressions.

Fixations are commonly interpreted as signs of processing new information. Eye fixations of skilled readers last between 200 and 250 ms on average (Pollatsek, Rayner and Collins 1984). Reading saccades or short rapid eye movements, which intermingle with fixations, cause the eye to move between 1 and 20 characters, with the average span being 7 to 9 letters. It is a widely accepted view that skilled readers show longer saccades, shorter average fixation durations and fewer regressions. Whether a word is fixated by a reader depends on its length and its word class. 85% of the content words and 35% of the function words are fixated while 2-3 letter words are skipped 75% of the time (Carpenter and Just 1983).

When processing information, saccades normally land between the beginning and the middle of a word (Morris, Rayner and Pollatsek 1990). A reader gathers information from a text at and around the fixation point. At this fixation point the text is perceived clearly and within a window of a certain character length the text appears normal. Outside this perceptual span the text is garbled. Depending on the size of this perceptual span we can distinguish between unaffected and impaired reading. When the window extends 3-4 letters to the left of the fixation and 14-15 letters to the right we talk about unaffected reading (see e.g. McConkie and Rayner 1976). The asymmetry of the perceptual span in reading is caused by the fact that readers typically move their eyes forward when reading. However, 10 to 15% of saccades move backwards. This happens when readers fixate previous letters or words. In a study dealing with the processing of anaphor Murray and Kennedy (1988) relate regressive saccades to difficulties in processing an individual word or to difficulties in processing the meaning or structure of a sentence. Readers tend to re-fixate parts of the text that causes comprehension problems.

The presentation format also plays an important role in the processing of information and influences eye movements. In a study monitoring reading speed, comprehension and task load on mobile phone screens Öquist and Lundin (2007) found that the paging format offers the best readability. Their results show that text presented in the page format is read significantly faster and yielded more regular eye movements than other presentation formats such as scrolling, or RSVP (Rapid Serial Visual Presentation). However, the presentation format did not significantly affect comprehension, a result which also holds true for this investigation.

Eye movements are also sensitive to inconsistencies in a text. Rayner et al. (2006) found out that readers fixated longer on regions were inconsistencies occurred, a finding which was also confirmed by the present study. However, we have to bear in mind that in hypertext inconsistencies are often the result of the fragmentation effect produced by the text structure.

Eye-movement data have been used to study lexical ambiguity, syntactic ambiguity and discourse variables such as inferences. However, some of the results drawn from these studies should be evaluated critically. Due to the complexity of cognitive processes and the great variability of fixation duration that exists between readers and within readers, the measures taken are often subject to systematic and/or random errors. While the average fixation duration for some readers is 200 ms, for other readers it is close to 300 ms. There are also enormous differences in the saccade length, which may vary between 6 and 10 letter spaces. Engbert and Nuthmann (2008) have found that distributions of within word landings of fixations are rather broad and show overlapping tails. Their approach is based on the iterative computation of the proportions of several types of oculomotor errors, the underlying probabilities for word-targeting, and corrected distributions of landing positions. Engberg and Nuthmann found that a fraction of the fixations, namely about 10% to 30% depending on word length, is mislocated. Their results indicate that fixation probabilities are affected by oculomotor errors.

2. The impact of hypertext structures on navigational behaviour

2.1. Experimental design

The main aim of this study was to find eye tracking evidence for the hypothesis whether navigational behaviour in hypertext is also dependent on its information structure. The study is a follow-up investigation of a test series conducted to evaluate the influence of hypertext structures on navigational behaviour, reading speed and comprehension (Reitbauer 2007), in which navigational behaviour was tested using recall protocols developed during interviews. Since the retrospective perspective is always subject to lapses of memory, a real time measurement such as eye tracking was considered to be an ideal means of verification.

The previous study had shown that prototypical hypertext structures, i.e. the typical information architecture in hypertexts such as the axial structure or the network structure, which were investigated by Landow (1994) and Engebretsen (2000), triggered prototypical navigational behaviour, i.e. readers chose paths that were influenced by the textual structure. To further analyse these prototypical reading paths a source text on the topic of speed reading consisting of 597 words was converted into an axial and a networked hypertext version. The subjects in this test series were 22 students of English and American studies from Graz University, who had passed a series of language courses corresponding to the level of C1 according to the common European Framework of Reference., To sample the position of the user's eye on an average of very 20 ms the Eye Tracker Tobii 1750 was used. The data were analyzed using the software program Clearview. The metrics used were the number of fixations overall, the sequence of fixations, dwell time mean and the mean number of fixations per area of interest. It was assumed that scan path data depicting the sequence of fixations would provide valuable insight into reader interaction with the hypertext and indicate the efficiency of the arrangements of elements in the surface text. It is important to mention at this point that pictures and other forms of media common in hypertext were deliberately excluded from the presentation format used since the main aim was to focus on the perception of text.

The subjects, 19 female and 3 male students of English and American Studies, were split into two groups. Each group was presented with one of the hypertext versions. The subjects had to read the text and then take a short comprehension test with 11 multiple-choice questions. To answer the comprehension questions the subjects did not have to resort to prior knowledge. All answers to the questions could be found in the text without having to make inferences.

Fig. 1 (see below) depicts the text as presented in the axial condition. Here three links are embedded in a central node which always remains on the screen. The text at the top with the heading ‘Is speed reading for you?’ also remains on the screen whenever a link is opened. The central node serves as a trunk which in our case has three "branches" with additional information which readers may choose to click on. Since the links are embedded in a running text, they indicate a recommended reading strategy. In Fig. 1 the link comprehension is opened, which is marked by a change in colour.

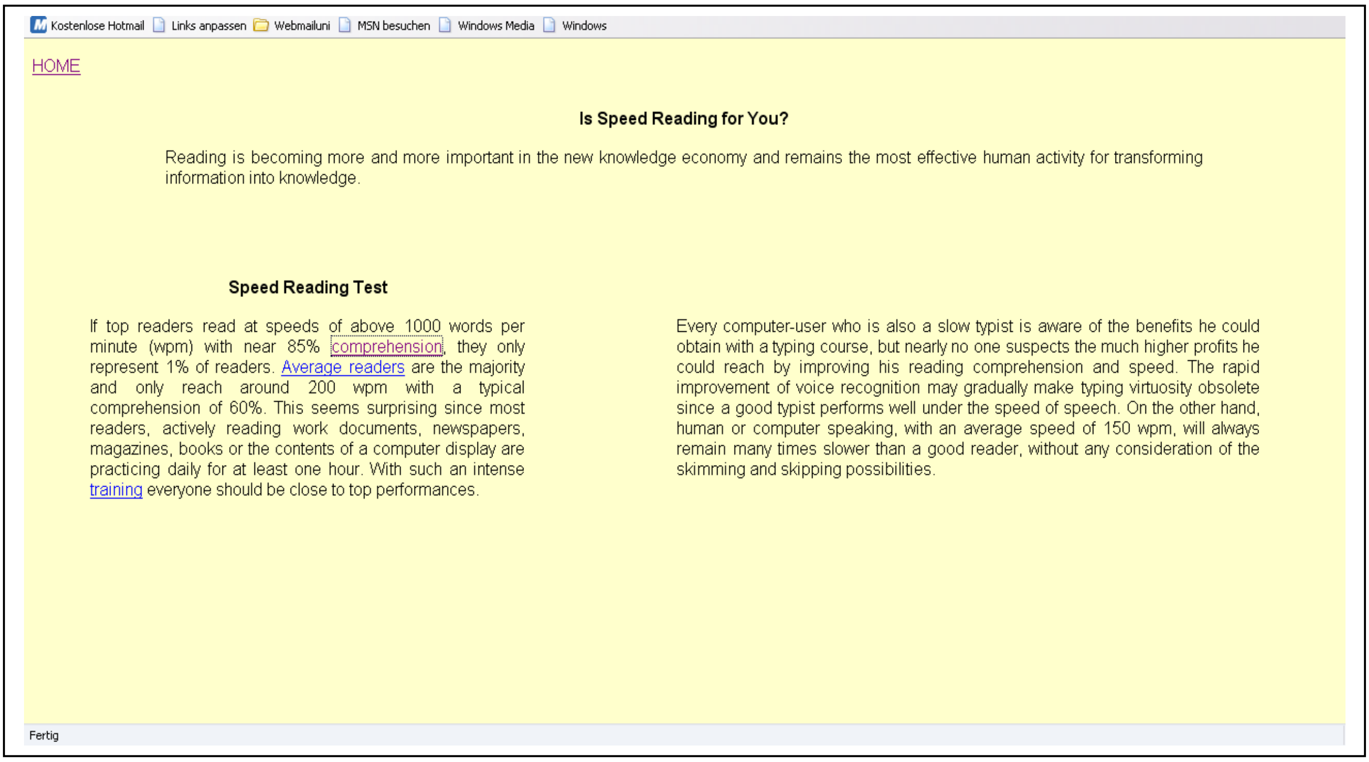

Fig. 1: Axial condition

Four areas of interest (AOIs) were defined in this condition in order to investigate eye tracking data that depict gaze replay and hot spot images of areas of highest fixation count: AOI 1: central link with no link opened; AOI 2: central link and link comprehension opened; AOI 3: central link and link average readers opened; AOI 4: central link and link training opened.

In the network condition (see Fig. 2) the same text was presented, this time with 7 links outside the main node. Networked hypertexts are characterized by the absence of a centering "trunk" or any other device to order the nodes (see Bertin 1981). Nodes are linked on the basis of semantic criteria, or other criteria which the hypertext designer applied. In this condition the reader is supposed to have more navigational freedom since the links do not indicate a hierarchy or suggest a preferable order in which they should be opened. The main node in this condition is entitled <u>speed reading test</u> and remains on the screen whenever other nodes are opened.

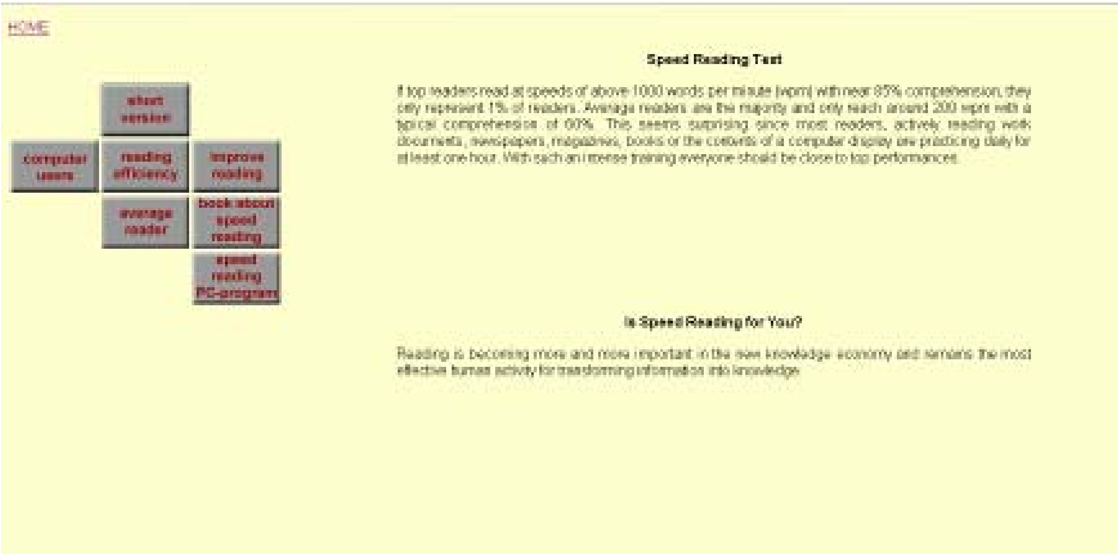

Fig. 2: Network condition

In order to control for the number and sequence of fixations and fixation duration eight areas of interest were defined, again on the basis intersection points in the text, i.e. points at which the readers had to decide which link to open next. It is important to note at this point that the texts in the two conditions were transformed verbatim and thus the number of words to be read was the same for both groups. In addition, the mean value for the number of fixations counted in each area of interest was weighted statistically according to the number of words to be read. This was necessary because the nodes in the network condition were shorter since the text had been split up into eight chunks.

2.2. Results

2.2.1 Scan paths as reflections of the textual structure

The scan path is one of the most important metrics measured by eye tracking systems. Scan path pictures of the defined areas of interest show the number and the order of fixations. Dots labeled with numbers in the scan path pictures represent fixations and connecting lines represent saccadic eye movements between the fixations. The pictures are very informative as far as the usability of a webpage and its global information structure are concerned.

Scan paths offer evidence to validate the user-friendliness of textual structures. They are therefore often used in the prototype testing of homepages. In a study conducted by Bojko (2006) it was found that the re-design of a homepage which in its old form had produced numerous and scattered fixations resulted in focused fixations due to a more clearly presented navigation design.

The fixations gathered in the present study show a similar focus of fixations around links and corresponding nodes. The analysis of scan path data reveals that the order in which links and nodes received first fixations was relatively stable throughout the two conditions. The scan path images show prototypical sequences of fixations made by the users and very effectively illustrate how individual users navigate in the two different hypertext structures.

The gaze patterns that emerged in the axial condition show clear prototypical tendencies. 91% of the subjects opened the links in the order of their occurrence in the main node. This can be verified by looking at the consecutive numbering of the fixations. The users' main paths through the text were further characterized by a focus on the node they had opened by clicking the link. Regressive eye movements only occurred when the readers got back to the central node to search for the next link to be opened or when comprehension problems occurred (see section 2.2.2.).

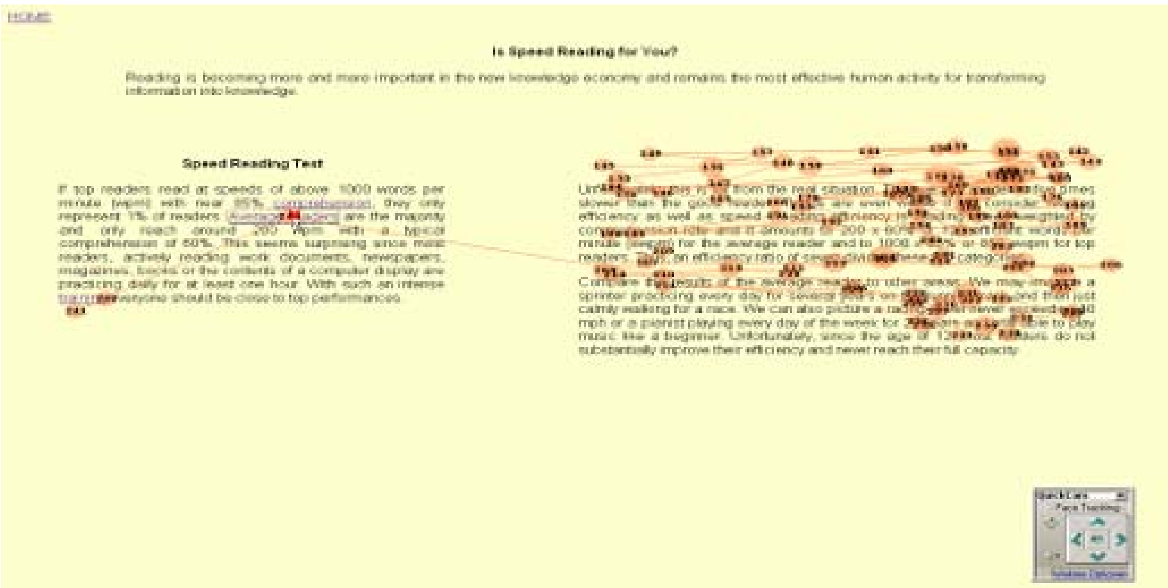

Fig. 3: Prototypical scan path in the axial condition

When we analyse the corresponding hotspot image that summarizes the gaze position, we see that the central node is only fixated to move on to the next link in the hierarchy (see the colour-coded map in Fig. 4, with red being the most viewed area, graduating down to light yellow to indicate less fixation time).

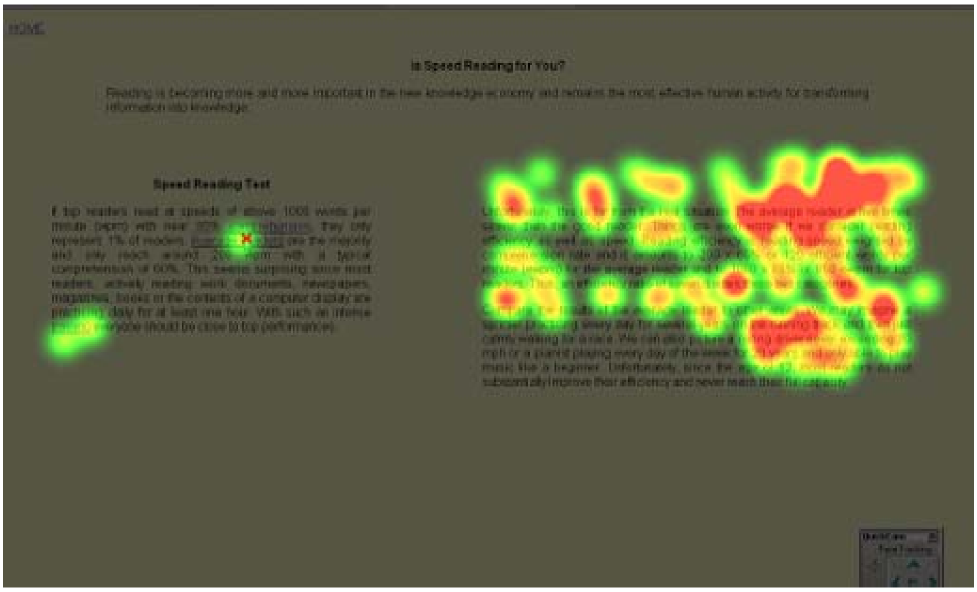

Fig. 4: Hotspot map of a prototypical scan path in the axial condition

In the network condition we can observe a similar tendency. There is a clear focus of fixations centred in the node opened and links are only fixated when readers decide to open the next node. However, due to the arrangement of links outside the main node the order in which the links were opened was not as homogenous as in the axial condition. Although there was some variation, the majority of readers, namely 73%, opened the links starting with the one at the top (<u>short version</u>) and then following a horizontal order from left to right (see Fig. 5 and 6). Again this finding confirms the results of the previous study, in which readers drew a retrospective log file of their path through the text (Reitbauer 2007).

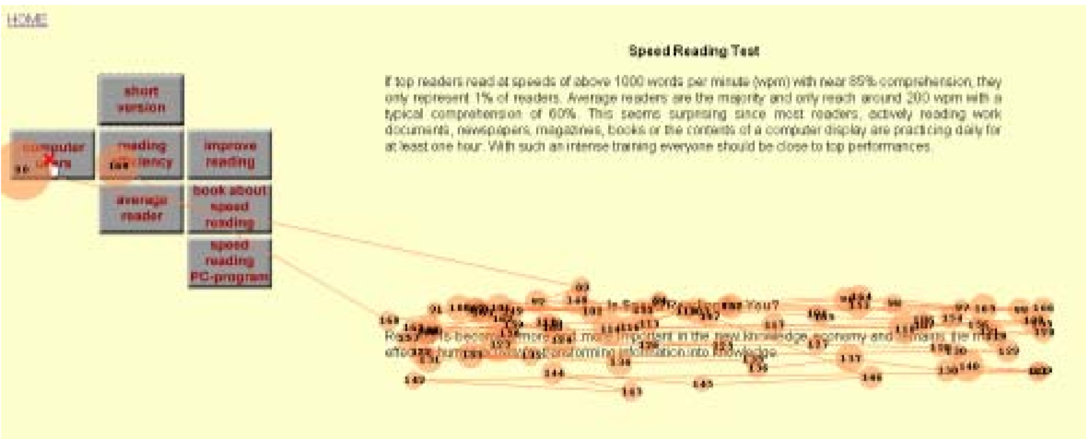

Fig. 5: Prototypical scan path in the network condition

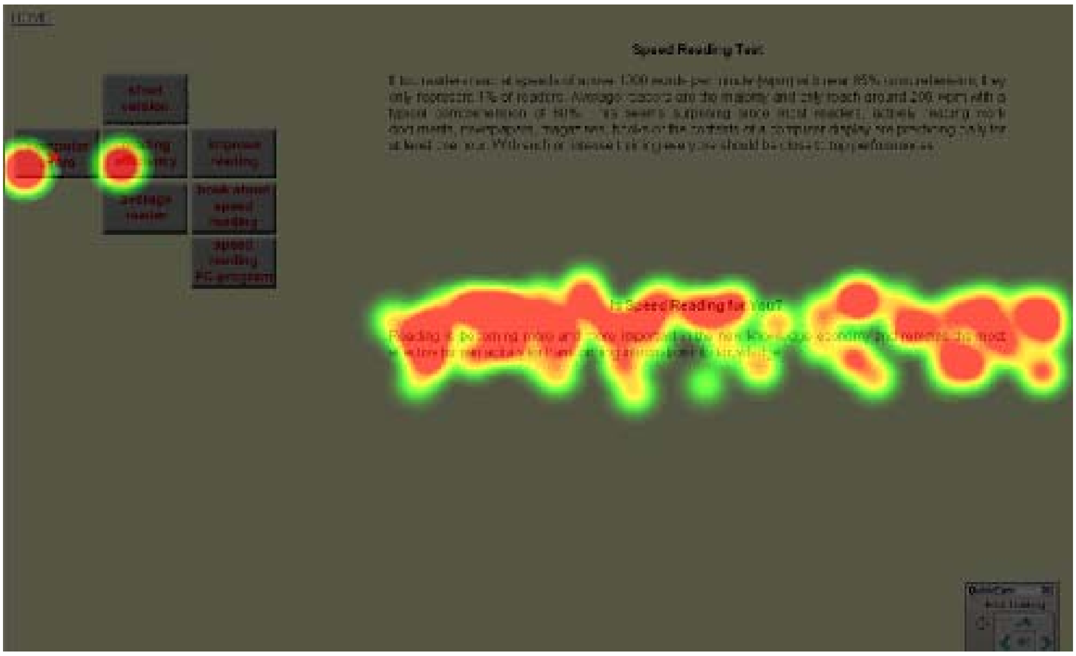

Fig. 6: Hotspot map of a prototypical scan path in the network condition

The analysis of scan paths shows that the feedback on navigational behaviour that users gave in the previous study is supported by eye-movement measurements. Gaze replays that were watched with readers during the interviews after the comprehension test confirm that navigational decisions were based on aspects of textual structure. These biometric measures were chosen for this follow up investigation because they are generally considered more reliable than data acquired through survey methods. They give a more accurate picture of the users' immediate experience in comparison to interviews after task completion.

If you compare the pictures of the prototypical paths in the previous study with the hot spot images and scan path pictures, you find that the preferred routes readers take through the text were identical in both studies.

In the axial condition the links were opened in the order of their occurrence in the running text of the main node (Fig. 7a: blue arrow = first link opened, red arrow = second link opened, green arrow = third link opened). The same behaviour was observed in the present study. As an example, Fig. 7b depicts how the reader moves from the second to the third link, which corresponds to a switch from the red to the green arrow in Fig. 7a.

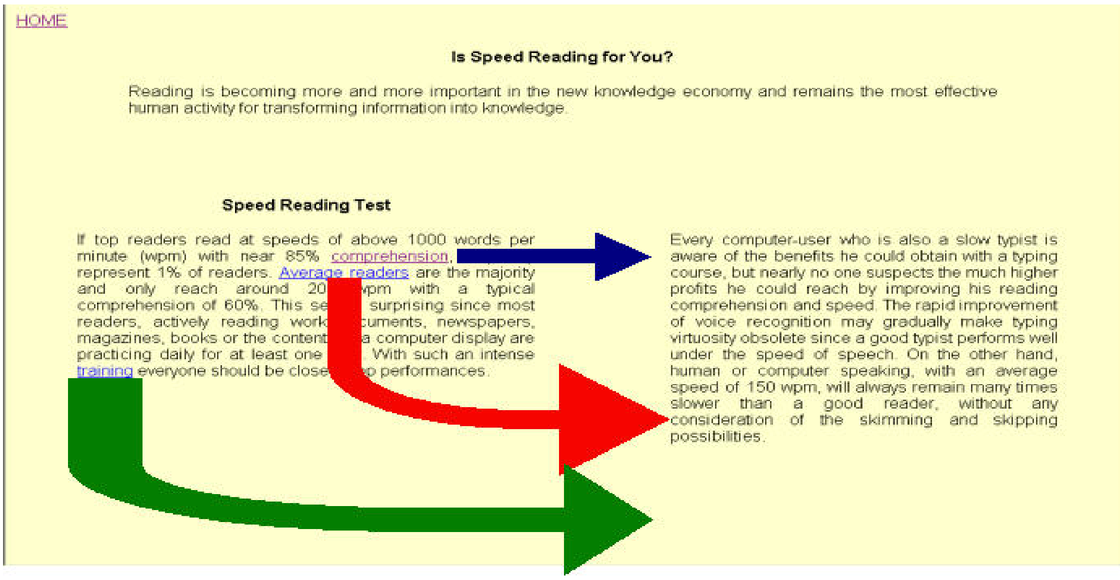

Fig. 7a: Prototypical paths in the axial condition (Reitbauer 2007)

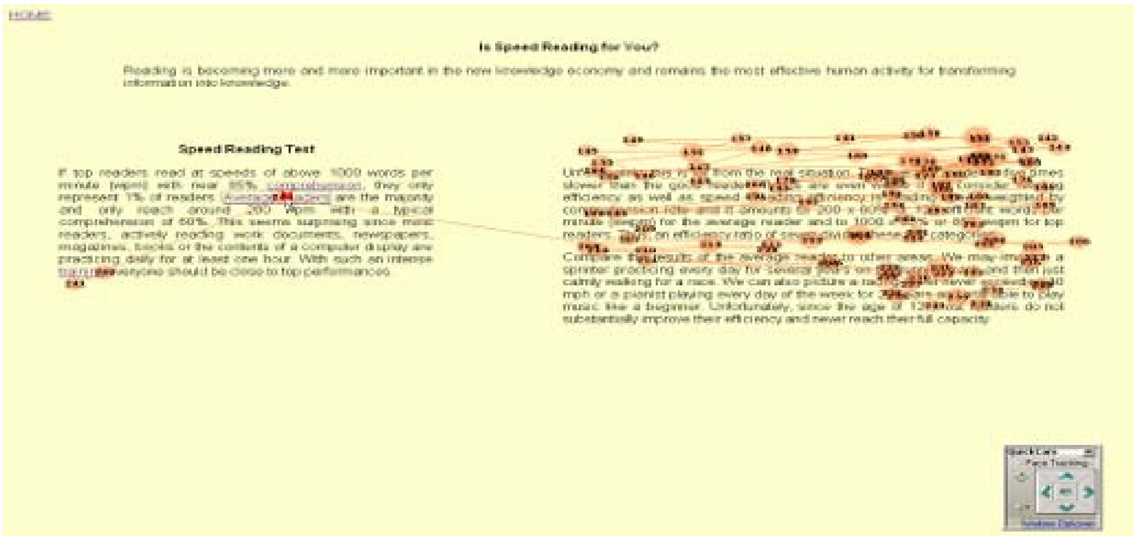

Fig. 7b: **Example of a corresponding scan path of current study**

In the network condition three paths were found to be dominant in both studies. The arrows in Fig. 8 illustrate the typical progression from link to link for each of these paths (red = path 1, green = path 2 and blue = path 3). A corresponding example from our current study is provided by the hotspot map in Fig. 6, which illustrates the switch from the second to the third link in path 1 (red spots in the top-left corner).

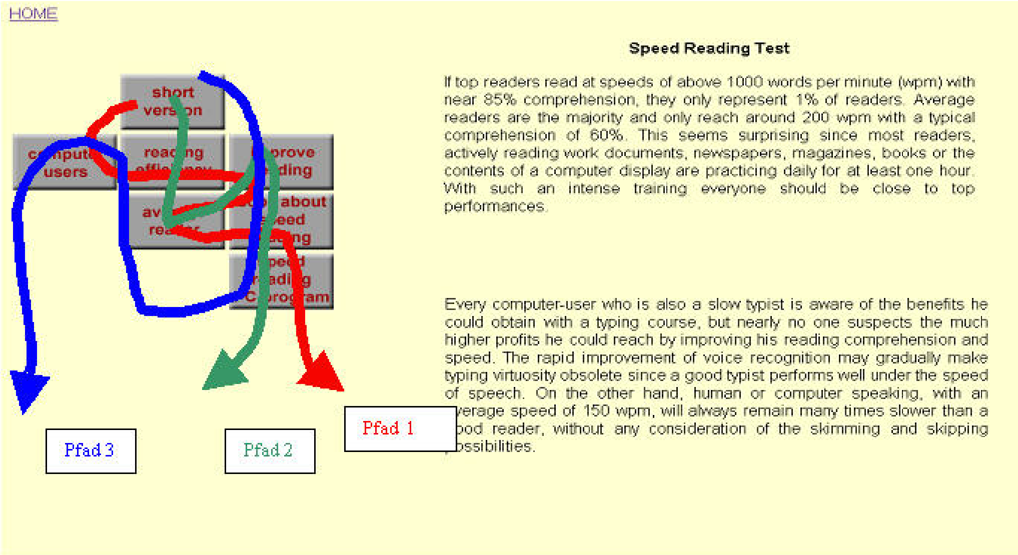

Fig. 8: Prototypical paths in the network condition (Reitbauer 2007)

2.2.2 Regressive eye movements as indicators of textual complexity and problems in the information architecture

Regressive eye movements have become an object of investigation since they are associated with comprehension problems, problems of text design and textual complexity. The readers refocus on elements that are either unusual in particular circumstances, unfamiliar or incomprehensible. Disruptions of the visual flow occur when the layout of the text does not guide the readers' eyes effectively through the whole document. Eye tracking data is thus very useful in detecting problems in the information architecture.

In the course of an ordinary reading situation the readers fixate on each word sequentially. They skip some of the words, fixate on others twice and sometimes regress to preceding words. The reader is often not aware of these regressions. Researchers assume that eye movements during reading are mainly controlled by reasonably low-level processes in the brain. Higher level processes only occur when something needs to be clarified and cognitive processes such as reasoning and inferring are involved.

About 10–15 % of the fixations are regressions to previously read words. Regressions are commonly accepted as indicators of higher-order cognitive processes and are often associated with text difficulty. Many studies have shown that text difficulty has a strong influence on the number of regressions the readers make. Regressions are triggered when readers encounter a word indicating that their prior interpretation of a sentence was wrong. Therefore it is likely that some of the regressions are due to comprehension failures (see Rayner 1998).

However, regressive eye movements can also be caused by oculomotor error. Findings of O'Regan (1990) and Engberg and Nuthmann (2008) support the idea that regressions are sometimes due to simple motor error because whenever the eyes fixate near the end of a word, they often move back a few character spaces because they have missed their intended target, which is usually near the middle of a word. The identification of a word is most rapid if it is fixated in its so called *optimal viewing position*, which is just to the left of the words centre (Clark and O'Regan 1999).

In the present study regressive eye movements occurred more often with readers who had low scores on the comprehension test. This was the case in both the axial and the network condition. Although no significant comprehension differences were found between the two conditions, a comparison of subjects who achieved the same comprehension score shows very similar patterns of regressions. The pattern of these regressions was found to be fairly consistent within the respective textual structures. In the axial condition regressive eye-movements were accompanied by long fixations and the pre-reading of the central node in which the links were embedded. In the network condition regressive eye movements only occurred within the node that had been opened. Moreover, the mean duration of fixations was shorter and the central node was not pre-read. The following figures illustrate the pattern of fixations of two subjects that had both achieved a low score on the comprehension test, namely 45%.

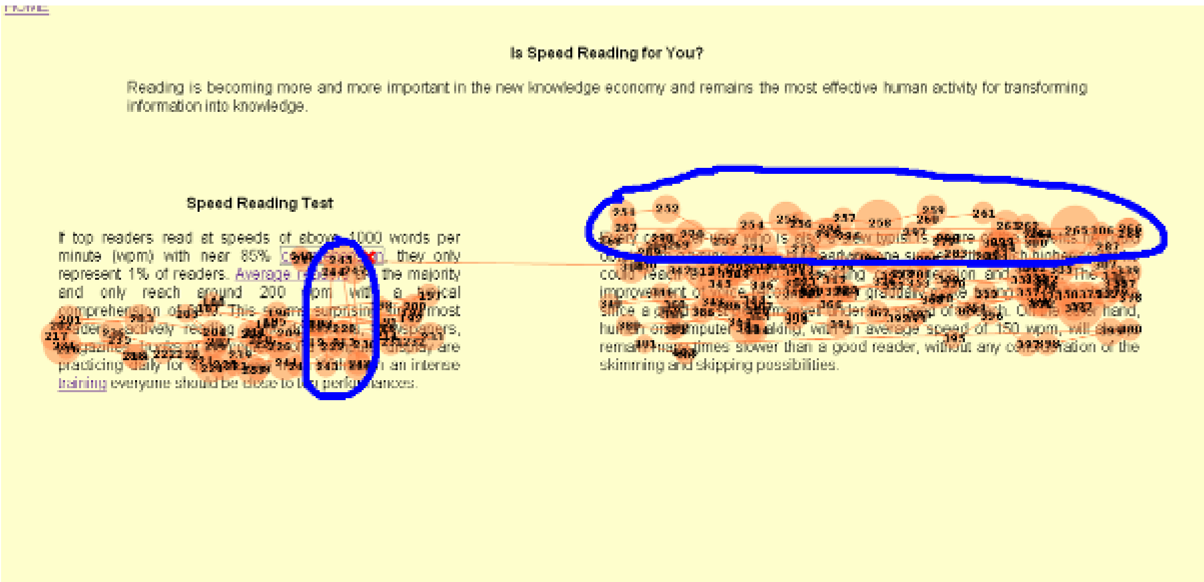

Fig. 9: Scan path of a reader with a low comprehension score (45%) in the axial condition

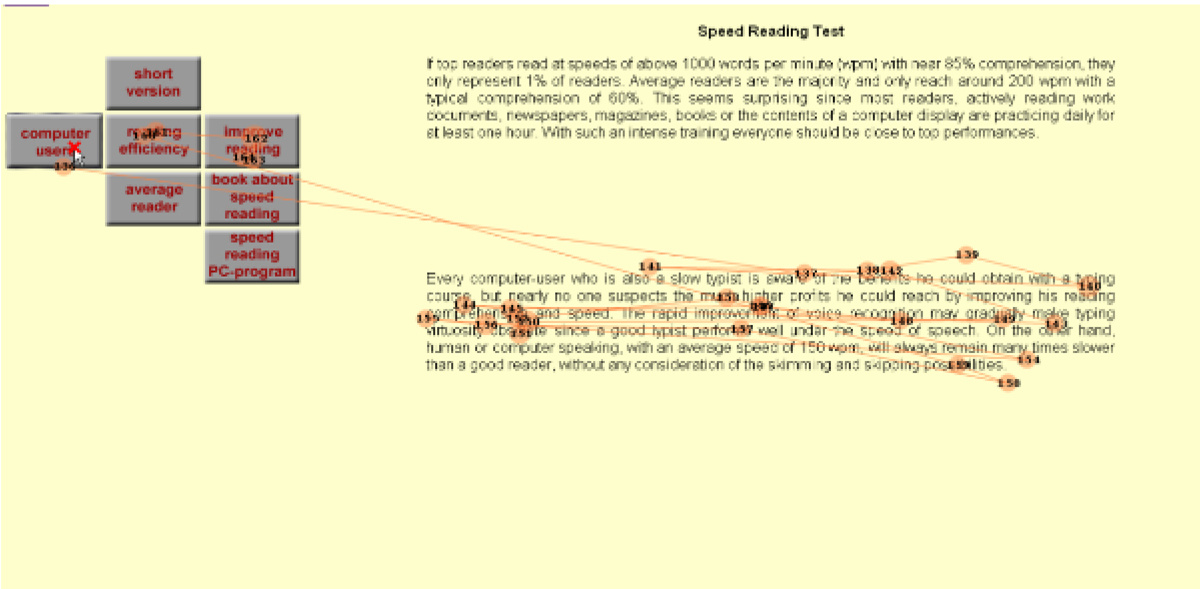

Fig. 10: Scan path of a reader with a low comprehension score (45%) in the network condition

A comparison of the two conditions shows that regressions may be related to both comprehension problems and/or text design. Regressive eye movements in the axial condition occur both in the central node that is pre-read before opening the next link and in the node opened while regressions in the network condition only occur within the node opened by the link. A possible explanation for this reading behaviour might be the contextualization of the links in the axial condition. Links that are embedded in co-text induce the readers to make use of this co-text to clarify or correct their interpretation of the text and help them decide which link to open next, while links outside a node that are not surrounded by contextual clues do not trigger regressive eye movements.

Another explanation for the different regressive behaviour in the two conditions might be the location of central node. In the network condition this text appears as a kind of header and many studies have shown that headers are often ignored by readers (see e.g. Nielsson and Loranger 2006).

When choosing links, less successful readers in both conditions either used the mixed navigation strategy or the mixed review navigation strategy, which were first defined by Protopsaltis and Bouki (2005). Choosing the mixed navigation strategy, the readers opened links without any discernable pattern. Making use of the mixed review navigation strategy, they scanned all available choices before selecting the next link to be opened. Fig. 11 illustrates the mixed review navigation strategy and shows examples of hot spot images for readers who performed poorly on the comprehension test. On the left you see the scan path in the network condition. On the right you see that the reader in the axial condition who fixates all links and the surrounding co-text again before opening the third link below (see blue arrow).

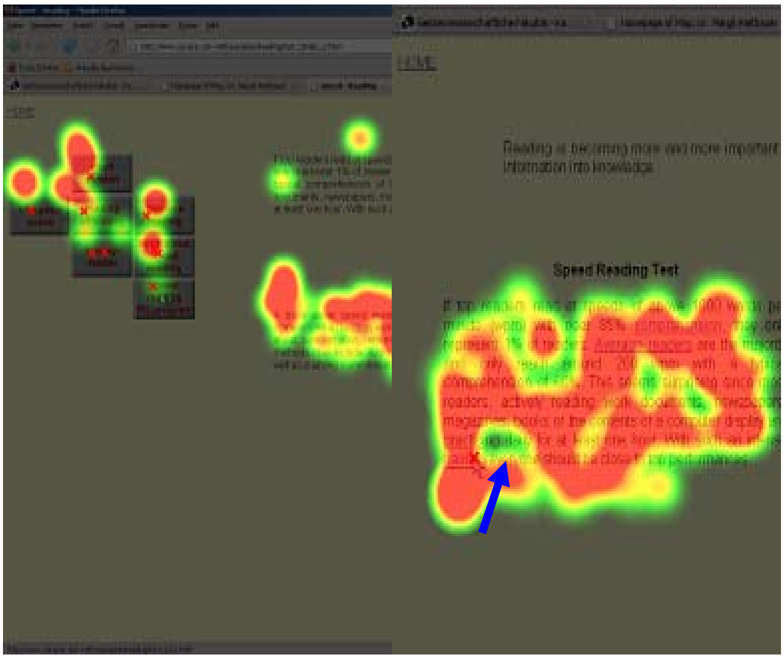

Fig. 11: Mixed review navigation strategy: scanning of links by unsuccessful readers

In comparison pictures of readers with top scores (91%) show longer saccades, fewer regressions and shorter durations of fixations on links.

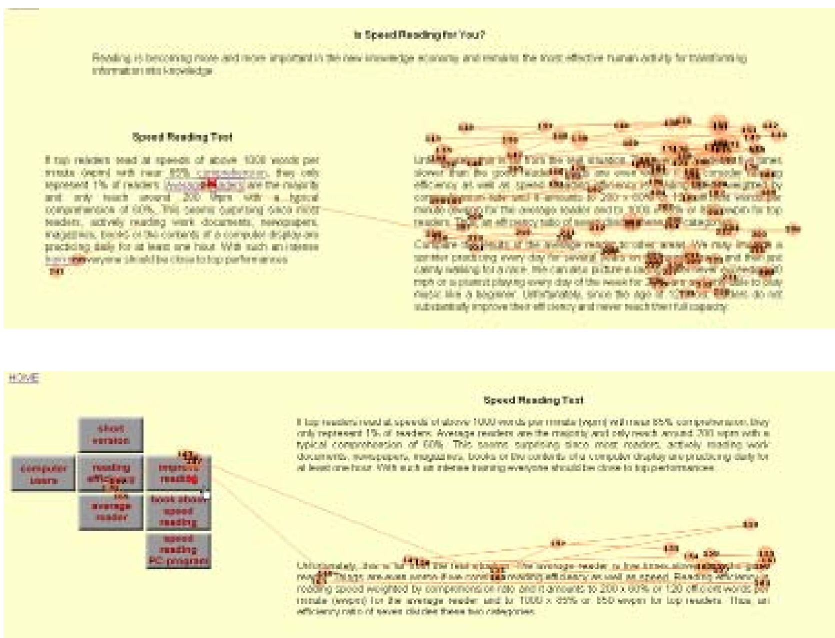

Fig. 12: Scan paths of highly skilled readers

In both conditions comprehension problems and regressive eye movements occurred with discourse markers that balance contrasting points (e.g. *on the other hand)* or introduce a counter argument (e.g. *however*). These discourse markers add to textual complexity and are therefore likely to trigger regressions. The following sentence triggered regressions:

> ***On the other hand,*** *human or computer speaking, with an average speed of 150 wpm, will always remain many times slower than a good reader, without any consideration of the skimming and skipping possibilities*.

36% of subjects in the network condition and 27% of subjects in the axial condition re-read the preceding sentence when encountering the discourse marker *on the other hand*. This finding is consistent with studies that show that regressions are triggered when readers assume that their first interpretation was wrong or is challenged by the following statements (see. e.g. Rayner 1998). Since discourse markers aim at making conceptual relationships clear it would be interesting to see in a follow-up investigation if hypertexts equipped with additional means such as navigable topical overviews that map conceptual relationships help to reduce comprehension problems in these areas. The findings of Naumann et al. (2007) indicate that hypertexts equipped with additional hypertext-specific signals may compensate for deficits in reading skill.

After discussing prototypical scan paths and regressive eye movements we will now turn to the analysis of the individual variables controlled for in this study, namely the number of fixations in the defined areas of interest, dwell time and comprehension.

2.2.3. Number of fixations and dwell time

The variables fixations and dwell time were chosen for the current investigation because they are commonly associated with the ease or difficulty of processing information. In general, higher numbers of fixations and longer fixation durations are related to difficulty in processing and both factors have an influence on when the eyes move.

The evidence of many empirical studies suggests that it is primarily the linguistic properties of words that are responsible for the decision of when to move. High frequency words are fixated for a shorter time than low frequency words (Just and Carpenter 1980, Vitu, Mc Conkie, Kerr and O'Regan 2001). Moreover, fixating low frequency words is often accompanied by the so-called *spillover effect,* which describes the fact that the fixation time on the next word is inflated by the longer fixation time of the low-frequency word read before (Rayner and Duffy 1986). Another factor that influences fixation and dwell time is the predictability of a word. Words that are highly predictable from the context are fixated for a shorter time or skipped (Ehrlich and Rayner 1981). The results of the present study confirm these findings and also indicate that fixations and dwell time are in fact dependent on linguistic properties of words rather than on aspects of textual structure. Many similarities concerning the fixations of numerals, negations and causal relations were found in both conditions.

A comparison of the two groups showed great differences in the number of fixations and in dwell time across groups and across individual subjects. In the axial condition the mean values for dwell time and number of fixations in the areas of interest was much higher than in the network condition (see Fig.13 and 14 below). However, due to the huge differences among individual readers and within readers the variance was too big to produce any significant effect. Neither the t-test nor the multivariate test produced effects that attained the level of significance.

	group	N	Mean	Std. Deviation	Std. Error Mean
fixations	axial	11	469,2727	333,36769	100,51414
	net	11	347,3636	146,85522	44,27851

Fig. 13: Group statistics fixations

	group	N	Mean	Std. Deviation	Std. Error Mean
dwell	axial	11	22678,8636	25726,84661	7756,93611
	net	11	6060,1255	2681,09068	808,37926

Fig. 14: Group statistics dwell time

Although the data gained did not provide statistical significance for a relationship between the independent variable *textual structure* and the dependent variables *dwell time* and *number of fixations* some interesting aspects of reading behaviour triggered by linguistic properties of words were revealed and proved to be similar in both conditions. We found interesting parallels as far as dwell time in connection with causal relations and numerals is concerned. The measure used for investigating these two items was gaze duration, which is the sum of all fixations on the words in question prior to moving to another word. These parallels will be discussed in the following.

It is commonly assumed that discourse markers expressing causal relations lead to increased reading speed (e.g. Just and Carpenter 1980). This was also the case in the present study in which words such *since*, *as* and *thus* either show short fixation times or are skipped by readers. Fixation duration was short with an average of 169 ms in the axial condition and 188 ms in the network condition. These findings are consistent with findings of Menno van der Schoot et al. (2008), who in their study on reading strategies in primary school children found that successful readers invest most of their processing time in content words and very little time in the processing of discourse markers.

However, in the current study causal discourse markers were fixated frequently, namely by 77% of readers in the axial condition and 66 % of readers in the network condition. In both conditions highly successful readers fixated for a shorter time while less successful readers invested a lot of processing time in them. With readers who had a low comprehension score causal discourse markers sometimes triggered the re-reading of the previous sentence (see Fig. 15, where this behaviour is illustrated for a *Thus* at the beginning of a sentence).

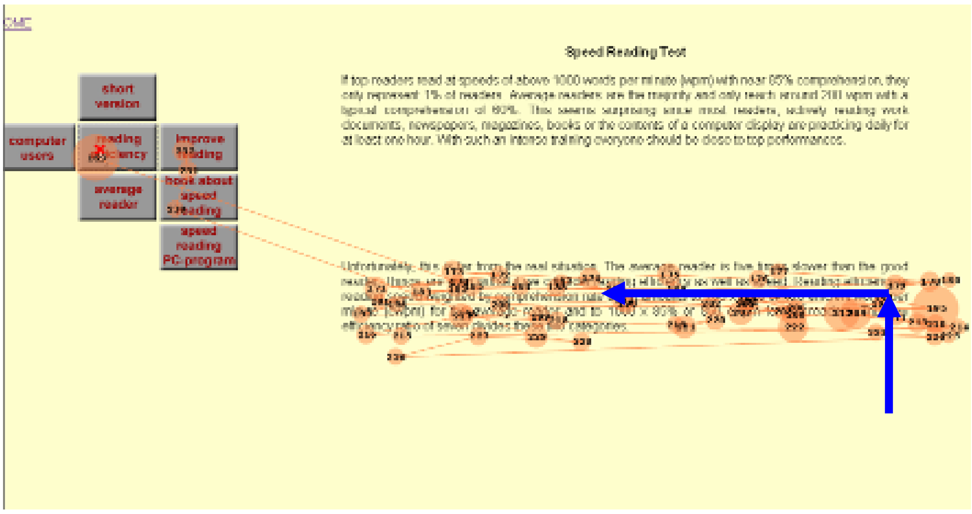

Fig. 15: Scan path of a reader who has difficulty in discovering the causal relationship between two sentences

In contrast to discourse markers numerals showed longer fixation durations in both conditions. Both successful and unsuccessful readers fixated numerals longer than other elements in the text. In the axial condition the average fixation duration on the five numerals in the central node was 360 ms while in the network condition it was 300 ms. The picture is similar with the node opened by the link average reader, which elaborates on the reading efficiency of average readers and contains nine numerals with an average fixation of 340 ms in the axial condition and 320 ms in the network condition. The following hot spot image (Fig.15) illustrates the long fixations on numerals in the network condition. The blue arrows point at figures that were fixated longer than 300 ms.

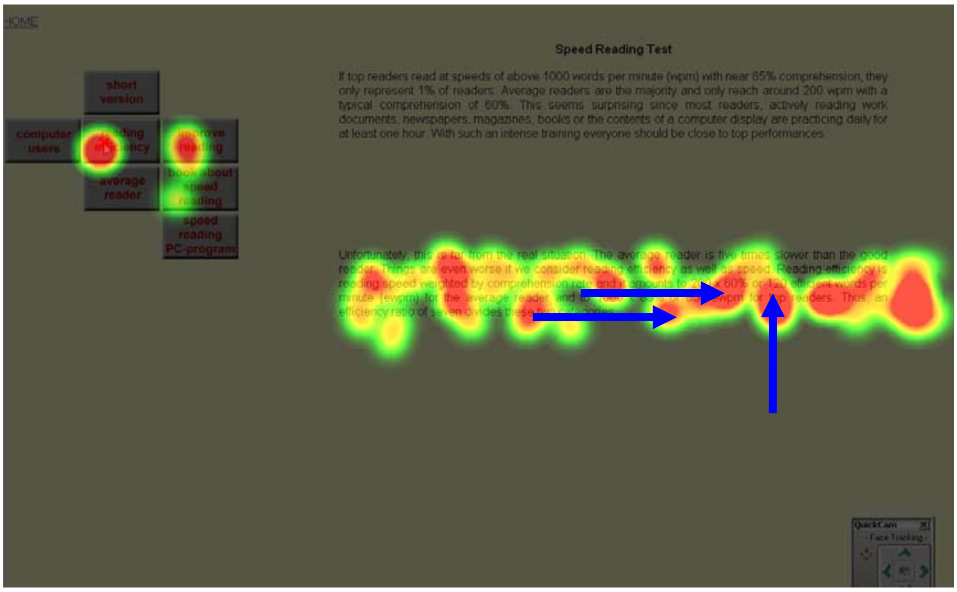

Fig. 16: Long fixations on numerals

These observations have to be interpreted with great care because they are the result of a descriptive analysis and therefore only hold true for this small sample of subjects. No statistical analysis was done for the data on dwell time on discourse markers and numerals.

2.2.4. Comprehension problems and textual complexity

In order to identify text passages that caused comprehension problems the scan path recordings of the defined areas of interest were analysed. As mentioned in Section 2.1. these areas of interest were defined at points in the text at which the readers had to decide where to go next, i.e. which link to open next. The mean value for the number of fixations counted in each area of interest was weighted statistically according to the number of words that had to be read in each area of interest. Dwell time was also controlled for. The sum of the individual fixations and their durations in the defined areas of interest were used as the primary measure.

The results of the comprehension test did not reveal any significant differences between the two groups. The mean comprehension score in the axial condition was 59.45 % while in the network condition it was 76.09 %

These results suggest that comprehension problems might be attributed to lexical and syntactical complexity rather than the presentation format. It is important to note at this point that the following discussion of text passages that proved to be difficult and thus showed a higher number of fixations and longer dwell does not claim to relate reading difficulties in these areas to the reading competence of the subjects since no statistical evidence was gained for this assumption.

If you compare the results of the multiple choice comprehension test you find that in both conditions the problematic questions, i.e. those that caused most comprehension problems were similar. In Fig. 17 you can see that questions 5, 7, 10 and 11 were difficult for readers in both conditions.

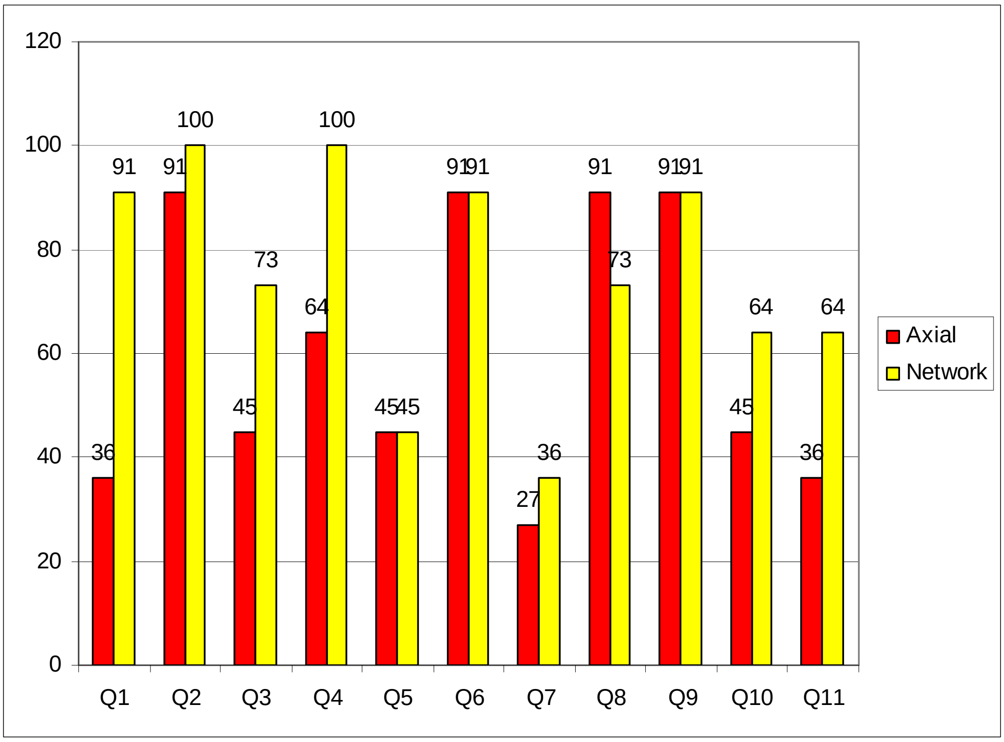

Fig. 17: Comprehension questions: comparison of results

Text passages containing metaphors caused comprehension problems. In both conditions only 45% of the readers answered question 5 correctly, which asked for a decoding of metaphors. The understanding of one idea in terms of another conceptual domain is a difficult task and involves the ability to map, i.e. to establish correspondence between the source domain from which the metaphor was drawn and the target domain that the reader tries to understand. This complex cognitive activity has been described by many linguists, e.g. by Lakoff and Johnson (1980). If you compare question 5 with the corresponding text passage

Q5. A sprinter running as the average reader reads, runs 100m in?

A 10 seconds (near record time)

B 35 seconds (jogging)

C 70 seconds (walking speed)

Compare the results of the average reader to other areas. We may imagine a sprinter practicing every day for several years on the running track and then just calmly walking for a race. We can also picture a racing driver never exceeding 30 mph or a pianist playing every day of the week for 20 years and only able to play music like a beginner. Unfortunately, since the age of 12, most readers do not substantially improve their efficiency and never reach their full capacity.

you can see that the series of comparisons using metaphors is introduced by the 'non-affirmative' expression '*We may imagine*' and we also find two other numerals which might have distracted the readers. The scan paths show that these two numerals were mostly fixated longer than the other elements in the text. Moreover, the metaphor for average reading speed with the sprinter walking for a race does not explicitly contain the figure "70 seconds" in the text, which might be another reason why many readers did not choose this item in the multiple-choice test and neglected the hint walking speed which is provided in brackets.

The second area of comprehension problems were numerals. As already mentioned, they were fixated long and often but they were only reproduced correctly when no transfer on the part of the readers was required. The answer to question 7 could be found in the text itself, where the numeral asked for is explicitly included. Nevertheless it required the ability to transfer the meaning relation of hyponymy from *human speaking or computer speaking* used in the text to *speaking speed of a race driver*, which was used in the comprehension question. This transfer was made even more difficult because the sentence is opened with the discourse marker *on the other hand*, which balances contrasting points that do not contradict each other (see Swan: 2005: 139). Moreover, the ability to decode a syntactically complex sentence was required from readers. The prepositional clause introduced by *without* contains a complex noun phrase, which makes it difficult for the reader to relate it to the main clause. The syntactic structure also creates a kind of end focus that might mislead the reader by seemingly putting informational weight on the last part, which is in fact only an extension. The long fixations and regressions in this last part could reflect the subjects' difficulties in interpreting this part of the text – at least if you proceed from a top-down approach that bases the interpretation of eye tracking data on a cognitive theory. In this case you could assume that fixations increase in number and duration when the material gets more difficult for the reader and when there are structural constraints on interpretation (see Goldberg et. al. 2002).

The following figure depicts regressive eye movements triggered by the complex *without* clause and shows a long fixation on the numeral asked for.

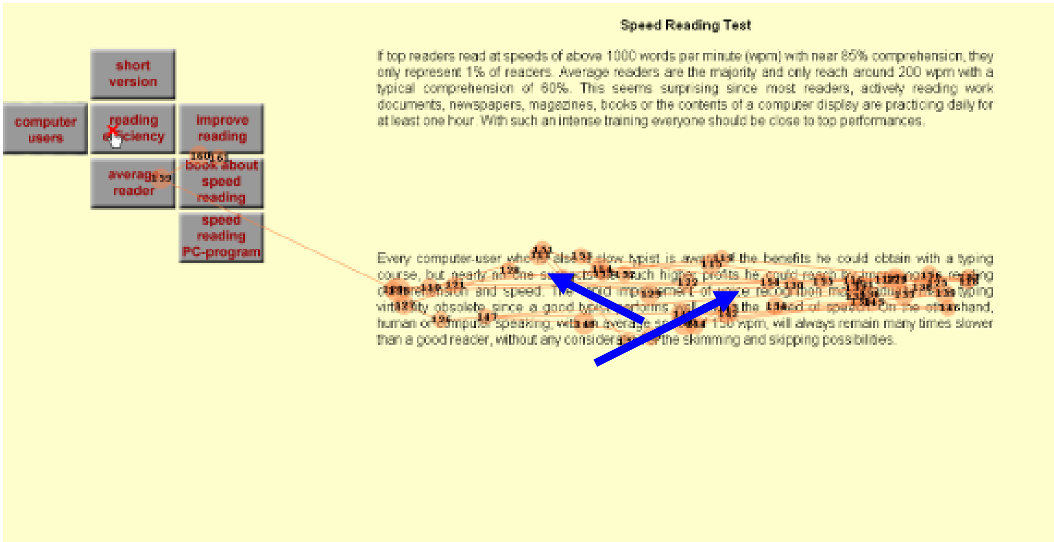

Fig. 18: Regressive eye movements triggered by syntactic complexity

The decoding of anaphoric reference also proved to be difficult for many readers. Question 10, which 55% of readers of the axial condition and 36% of the network condition did not answer correctly, involved the identification of an anaphoric reference established through *This is the task* at the beginning of the last sentence, which refers back to *giving the consistent practice offered by speed reading software,* asked for in Question 10.

Finally, comprehension problems were caused by the use of synonyms. The ability to detect and interpret synonyms was decisive as far as question 11 was concerned. Only 36% of the readers in the axial condition answered this question correctly while 64% in the network condition were able to do so. Finding the correct answer involved relating the terms *speed reading computer program* used in the text passage and the synonym *speed reading software* that was used in the question.

It is interesting to notice that the difference in the scores achieved in connection with question 11 was rather big between the groups. A possible explanation for this effect might be the fragmentation effect produced by the different presentation formats. The readers in the network condition were confronted with a shorter node which was opened after clicking the link speed reading pc-program. The fact that this additional link contains another synonym might have helped to memorize the concept and could have functioned as an additional cohesive device. In the axial condition the speed reading program appeared at the end of the node as one of three possible ways of training suggested after the readers had clicked on the link training.

3. Conclusion and critical evaluation of the results

In this study eye movement data were seen as a means of accessing the moment-to moment comprehension process in readers. The metrics used in this study, i.e. number of fixations overall, dwell time mean and number of fixations on the individual areas of interest produced results that showed great inter-reader and intra-reader variation. Thus, no significant differences between the groups were found. Nevertheless the results provided valuable insights into prototypical navigational behavior triggered by hypertext structures.

The statistical results of this pilot study with two relatively small experimental groups might have been influenced by individual differences between the subjects and their screen-based reading behaviour, which involved very complex cognitive activities such as browsing and scanning strategies as well as selective reading, which due to their interrelatedness are difficult to evaluate. The high between-subject variability may also be due to influences of low-level perceptual factors such as attentional shifts. Critics of eye tracking say that data have to be interpreted carefully since, whenever the brain is planning an eye-movement, it shifts covert attention to the eye's destination (see Peterson et. al. 2004). This attentional shift questions the eye-mind hypothesis because we may also find traces of attention to something that one is not looking at. In such a case eye tracking would not indicate cognitive processing at all.

In conclusion we can say that the comprehension problems were similar across groups and seemed to be independent of the hypertext structure. In both groups comprehension difficulties were accompanied by higher numbers of fixations, longer fixation durations and regressive eye movements. A comparison of subjects' comprehension results and corresponding text passages showed that eye movements seemed to be sensitive to global text passage difficulty and inconsistencies in text created through lexical ambiguity or syntactic complexity.

Since the main aim of this study was to find eye tracking evidence for the influence of hypertext structures on navigational behaviour, a descriptive approach to data evaluation was chosen and the sequence and the length of fixations were taken as primary metrics for the evaluation of data. Although there are many computational models such as the E-Z reader model (Reichle, Pollatsek, Fisher and Rayner, 1998; Reichle, Rayner, and Pollatsek, 1999) that provide a theoretical framework for understanding how word identification, visual processing, attention, and oculomotor control jointly determine when and where the eyes move during reading, such data were not included because they do not reveal information on strategies behind navigational decisions that are taken. Such data can only be gathered in interviews or recall protocols. Thus, the data about navigational strategies which had been collected in a previous study (Reitbauer 2007) were reassessed in this follow-up study using real-time measurement. The findings largely verified the data collected in interviews. It was found that the fragmentation of the text through a higher number of links in the network condition was experienced as beneficial for the recognition of semantic relations. Moreover, the hierarchical organisation of links in the axial condition made readers open the links in the order of their appearance in the main node. Links outside the main node arranged on a criss-cross basis caused a greater variety of navigational paths and sometimes led to orientation problems. As far as reading comprehension results are concerned, the previous study with 60 participants produced a significant effect in that the axial group showed better results (p=,005, Duncan Post Hoc Test). This finding could not be verified in this follow up study.

Summing up we can say that the use of eye-tracking data can enhance our understanding of the navigational processes in hypertext in areas such as processing mechanisms and attentional distribution. However, for a more comprehensive approach and an in-depth understanding of the reading process we need to include other methods of research such as computational and qualitative approaches. We have to find out why and how navigational decisions are taken because it is not enough to only record where and when readers change paths.

Bibliography

Bertin, J. (1981). *Graphics and graphic information-processing.* New York: Walter de Gruyter.

Bojko, A. (2006). Using Eye Tracking to Compare Web Page Designs: A Case Study. In: *Journal of Usability Studies*, Issue 3, (1). 112-120.

Card, S. K. (1984). Visual search of computer command menus. In: H. Bouma and D. G.Bouwhuis (eds), *Attention and Performance X, Control of Language Processes*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Carpenter, P.A. and M.A. Just (1983). What your eyes do while your mind is reading. In: K. Rayner (ed.). *Eye movements in reading: perceptual and language processes.* New York: Academic Press. 275-307.

Clark, J. J. and J.K. O'Regan (1999). Word ambiguity and the optimal viewing position in reading. In: *Vision Research,* (39), 843-857.

Delabarre E.B. (1898). A method of recording eye-movements. In: *Psychological Review* (8), 572–74.

Dodge and Cline (1901). The angle velocity of eye movements. In: *Psychological Review,* (8), 145-157.

Duchowski, A. T. (2003). *Eye tracking methodology: Theory and practice*. London:Springer-Verlag Ltd.

Ehrlich, S.F. and K. Rayner (1981). Contextual effects on word perception and eye movements during reading. In: *Journal of Verbal Learning and Verbal Behavior* (20), 641-655.

Engbert, R. and A. Nuthmann (2008). Self-consistent Estimation of Mislocated Fixations during Reading. In: *PLoS ONE 3 (2).* e1534.

Engebretsen, M. (2000). Hypernews and coherence. In: *Journal of Digital Information.* Vol. 1(7), 209-225.

Erdmann B. and R. Dodge (1898) *Psychologische Untersuchung über das Lesen auf experimenteller Grundlage*, Niemeyer: Halle.

Fitts, P. M., Jones, R.E. and J.L. Milton (1950). Eye movements of aircraft pilots during instrument-landing approaches. *Aeronautical Engineering Review*, 9(2), 24-29.

Goldberg, H. J., and X.P. Kotval (1999). Computer interface evaluation using eye movements: Methods and constructs. In: *International Journal of Industrial Ergonomics*, (24), 631-645.

Goldberg, H. J. and A.M. Wichansky (2003). Eye tracking in usability evaluation: A practitioner's guide. In: J. Hyönä, R. Radach, & H. Deubel (eds.), *The mind's eye:Cognitive and applied aspects of eye movement research* . Amsterdam: Elsevier. 493-516.

Goldberg, J. H., Stimson, M. J., Lewenstein, M. Scott, N., and A.M. Wichansky (2002). Eye tracking in web search tasks: Design implications. In: *Proceedings of the Eye TrackingResearch & Applications Symposium 2002* (pp. 51–58). New York ACM.

Hartridge, H. and L.C. Thompson (1948). Methods of investigating eye movements, *BritishJournal of Ophthalmology*, (32), 581–591.

Javal E (1878) Essai sur la physiologie de la lecture. In : *Annales d'ocullistique* (80), 61–73.

Judd, C.H., McAllister, C.N. and W.M. Steel (1905). General introduction to a series of studies of eye movements by means of kinetoscopic photographs. In: J.M. Baldwin, H. C. Warren & C.H. Judd (eds.) *Psychological Review, Monograph Supplements*. (7): The Review Publishing Company: Baltimore, 1-16.

Just, M. A. and P.A. Carpenter (1976a). Eye Fixations and Cognitive Processes. In: *Cognitive Psychology, 8*, 441–480.

Just, M. A. and P.A. Carpenter (1976b). The role of eye-fixation research in cognitive psychology. In: *Behavior Research Methods & Instrumentation, 8*, 139–143.

Just, M. A. & Carpenter, P. A. (1980). A theory of reading: From eye fixations to comprehension. In: *Psychological Review* (87), 329-354.

Kowler, E. (ed.) (1990). *Eye Movements and their Role in Visual and Cognitive Processes*. Amsterdam: Elsevier Science.

Lakoff, George & Johnson, Mark (1980) *Metaphors We Live By*. Chicago: University of Chicago Press.

Lamare M (1893). Des mouvements des yeux pendants la lecture. In: Comptes rendus de la société française d'ophthalmologie, 35–64.

Law, B., Atkins, M. S., Kirkpatrick, A. E., and A.J. Lomax (2004). Eye gaze patterns differentiate novice and experts in a virtual laparoscopic surgery training environment. In: *Proceedings of the Eye Tracking Research and Applications Symposium* . NY: ACM Press, 41-48.

Levine, J. L. (1984). Performance of an eyetracker for office use. In: *Computational Biology and Medicine*, (14), 77–89.

Mackworth, J.F. and N.H. Mackworth (1958). Eye fixations recorded on changing visual scenes by the Television eye-marker. In: *Journal of the Optical Society of America*, (48), 439-445.

Mackworth, N. H. and E.L. Thomas (1962). Head-mounted eye-marker camera. In: *Journal of the Optical Society of America*, (52), 713–716.

McConkie G.W. and K. Rayner (1976). Asymmetry of the perceptual span in reading. In: *Bulletin of the Psychonomic Society*. 8(5), 365-368.

Morris, R. K., Rayner, K. and A. Pollatsek (1990). Eye movement guidance in reading: The role of paravoveal letter and space information. In: *Journal of Experimental Psychology: Human Perception and Performance*. 16(2), 268-281.

Murray, W.S. and A. Kennedy (1988). Spatial coding in the processing of anaphor by good and bad readers: Evidence from eye movement analyses. In: *Quarterly Journal of Experimental psychology: Human Experimental psychology*. 40(4-A), 693-718.

Naumann, N, Richter, T. Flender, J., Christmann, U. and Norbert Groeben. (2007). 'Signaling in Expository Hypertexts Compensates for Deficits in Reading Skill.' In: *Journal of Educational Psychology* 2007, 99(4), 791-807.

Nielsen, J. and H. Loranger (2006). *Prioritizing Web Usability*. Berkeley CA: New Riders Press.

O'Regan, J.K. (1990). Eye movements in reading. In: E. Knowler (ed.) *Eye movements and their role in visual and cognitive processes.* Amsterdam: Elsevier, 395-453.

Öqist, G. and K. Lundin (2007). Eye movement study of reading text on a mobile phone using paging, scrolling, leading, and RSVP. In: *ACM International Conference Proceeding Series Vol. 284 : Proceedings of the 6th international conference on Mobile and ubiquitous multimedia* .Oulu, Finland , 176-183.

Peterson. M.S., Karmer. A.F. and D.E. Irwin (2004). Covert shifts of attention precede involuntary eye movements. In: *Percept Psycholys.* (66), 398-405.

Pollatsek, A., Rayner, K. and W.E. Collins (1984) Integrating pictorial information across eye movements. In: *Journal of Experimental psychology: General, 113 (3),* 426-442.

Poole, A., Ball, L. J., & Phillips, P. (2004). In search of salience: A response time and eye movement analysis of bookmark recognition. In: S. Fincher, P. Markopolous, D. Moore, and R. Ruddle (eds.), *People and Computers XVIII-Design for Life: Proceedings of HCI 2004*. London: Springer-Verlag Ltd.

Rayner, J. and S. A. Duffy (1986). Lexical ambiguity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. In: *Memory and Cognition* (14) 191-201.

Rayner, K. and A. Pollatsek (1989). *The psychology of reading.* Englewood Cliffs, NJ: Prentice Hall.

Rayner, K. (1998) Eye movements in reading and information processing: 20years of research. In: *Psychological Bulletin*, 124 (3), 372- 422.

Reichle, E .D., Pollatsek, A ., Fisher, D. L and K. Rayner (1998). Toward a model of eye movement control in reading. In: *Psychological Review*, (105), 125-157.

Reichle, E. D., Rayner, K., & Pollatsek, A. (1999). Eye movement control in reading: Accounting for initial fixation locations and re fixations within the E-Z Reader model. In: *Vision Research, 39*, 4403-4411.

Reitbauer. M. (2007). Die Textstruktur als Navigationssystem: Lesepfade und ihre Auswirkung auf das Verstehen von Informationen im Medium Hypertext. In: ESP and Professional Education: An International Journal of Linguistics. Kopenhagen, 49-73.

Shackel, B. (1960). Note on mobile eye viewpoint recording. In: *Journal of the Optical Society of America*, (59), 763–768.

Swan, M. (2005). *Practical English Usage*. Oxford: Oxford University Press.

Vitu, F., McConkie, G. W., Kerr, P., and J.K. O'Regan (2001). Fixation location effects on fixation durations during reading: An inverted optimal viewing position effect. In: *Vision Research* (41), 3513-3533.

Yoon, D. and N.H. Narayanan (2004). Mental imagery in problem solving: An eye tracking study. In: *Proceedings of the Eye Tracking Research and Applications Symposium 2004*. NY: ACM Press, 77-83.

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